System for voltage stabilisation of power supply lines

The invention relates to a system for voltage stabilisation of power supply lines, comprising a variable inductance, an autotransformer and a system for controlling the variable inductance with the object of automatically compensating for voltage variations that may arise in power supply lines.

The system is a further development of the system described in the applicant's Norwegian application no. 20015690 which is hereby included as reference in its entirety.

Transmission lines for electric power with too low a cross section in relation to the load requirement (so-called "weak" lines) will give a drop in voltage and thereby losses on the line, which in turn may result in an inadequate voltage level for the subscriber. The low voltage level can be compensated by increasing the voltage in steps from the transformer that provides the line with voltage. This is currently implemented by means of an on-load tap changer on the transformer physically mounted on the individual phase at the location where the voltage reaches an unacceptably low level.

A transformer is a static unit which supplies a fixed voltage in relation to the number of windings chosen on the primary and secondary sides.

The fixed voltage may produce an unfortunate effect since the voltage from the transformer will be too low when the load is high and correspondingly too high when the load is low. The load is dependent at all times on the individual subscriber's requirements and consumption and will be an extremely dynamic parameter.

The problem of lines that are too "weak" is solved at present by replacing existing lines with new lines with an upgraded cross section according to the increased requirement. Several methods are in use today for upgrading the actual line. It there is room on the pole, a new line can be extended on the other side of the pole in parallel with the "weak" line. When the new line is installed, the old one is cut and the subscriber is upgraded without any noticeable break in voltage. Method number two for the "weak" line is to prepare the attachments for the new lines to the existing pole, cut the "weak" lines and quickly set up new lines. This results in a longer break in voltage. The third method comprises laying a new route in cases where the old one cannot be used for various reasons. This involves new poles, line material, but not least the approval of departments and various landowners.

An alternative solution to the static upgrading once existed, using a mechanically controlled variac (i.e. a transformer with variable transformer ratio) in connection with a transformer. This solution is no longer in use since the mechanical components caused major operational problems. Such units have therefore been phased out today.

A final method that is employed is both costly and extensive. It consists of moving the actual high-tension line (20 kV) closer to the users and mounting a new distribution transformer there. This is also a method that people try to avoid due to its extent and costs.

A dynamic voltage booster, (i.e. a dynamic unit which can increase the line's voltage as required and which otherwise adjusts the voltage in the line to a desired value) will be a more efficient alternative compared to all the above-mentioned methods for improving "weak" lines. A unit can hereby be inserted in the line which is weak and dynamically compensate for the load-dependent voltage drop.

The method for obtaining a dynamic booster is to employ an electronically controlled inductance. Together with a transformer, a variable output voltage will be obtained which compensates for undesirable drops in voltage.

The invention therefore consists of a voltage stabilisation system for power supply lines comprising: a) an autotransformer with a series winding and a parallel winding, b) a variable inductance with a main winding coupled to the autotransformer and a control winding which is orthogonal to the main winding, c) a control system for controlling the current in the control winding as a function of the line's desired and actual operating parameters.

As stated, the invention permits existing "weak" lines to be adapted in a simple and inexpensive manner when there is an increase in energy requirements. The adaptation is implemented by the voltage stabilisation system being coupled to the installation between the distribution transformer and the users.

The function of the autotransformer is to add a voltage in series with the supply voltage, thus enabling the line voltage to be stabilised. The function of the variable inductance is to regulate the voltage across the inductance (by altering the permeability of the inductance core) or the time voltage integral across it in such a manner that the voltage across the series winding in the autotransformer can be regulated.

This voltage stabilisation must be performed quickly in order to avoid damage to equipment on the user side, as damage of this kind could occur if a rapid change of load leads to a higher voltage than is permissible. With the system according to the

invention the changes in the voltage will be controlled by means of the current in the control winding, and the system therefore has low inertia and will be able to absorb voltage peaks and troughs in a satisfactory manner.

The regulating system supplies power to the control winding in the variable inductance based on measurements and desired values with the result that the output voltage keeps to the desired value.

The invention will now be described in detail by means of the attached drawings, in which:

figure 1 illustrates an autotransformer,
figure 2 illustrates a first embodiment of the invention,
figure 3 illustrates a second embodiment of the invention,
figure 4 illustrates a third embodiment of the invention,
figure 5 illustrates a general block diagram of the invention,
figure 6 illustrates the embodiment in figure 2 in greater detail,
figure 7 illustrates the control of the embodiment in figures 6 and 8,
figure 8 illustrates the embodiment in figure 4 in greater detail,
figure 9 illustrates the embodiment in figure 3 in detail,
figure 10 illustrates the control of the embodiment in figure 9,
figure 11 illustrates a three-phase embodiment of the invention,
figure 12 illustrates the control of the embodiment in figure 11,
figure 13 illustrates a second three-phase embodiment of the invention,
figure 14 illustrates the control of the embodiment in figure 13,
figure 15 illustrates a third three-phase embodiment of the invention,
figures 16-18 illustrate the control of the embodiment in figure 15.

Figure 1 illustrates an autotransformer (i.e. a transformer where the primary winding and the secondary winding have a common part) T1 with a series winding S and a parallel winding P. The series winding S has few turns (approximately 20 turns) while the parallel winding P has many turns (approximately 230 turns).

In a first embodiment of the invention (figure 2) the series winding S is directly connected in series with the power supply line (LI: line in – LU: line out). In this embodiment the parallel winding is connected to the second phase (L: the line) via a variable inductance LR. The voltage in the series winding S can be changed here by changing the voltage in the parallel winding by means of the variable inductance.

In a second embodiment of the invention (figure 3) the variable inductance LR and the series winding S are connected in series with the power supply line (LI – LU), with the variable inductance on the LI side. The parallel winding is connected directly to the next phase (L: line).

In a third embodiment of the invention (figure 4) the variable inductance LR and the series winding S are connected in series with the power supply line (LI – LU), with the variable inductance on the LU side. The parallel winding is connected directly to the next phase (L: line).

In the second and the third embodiment of the invention the voltage in the power supply line LI – LU will be changed by the variable inductance LR absorbing a time voltage integral that remains in series with the voltage from the autotransformer's series winding S.

A more detailed description of the regulating system will now be given.

Figure 5 illustrates a block diagram of the voltage stabiliser with control system (regulating system) and the voltage stabiliser as separate blocks. The power supply line passes through the voltage stabiliser which is controlled by a control system. K1, K2 and K3 are switches which will connect and disconnect the voltage stabiliser to and from the system. In the figure K1 is illustrated in a closed state while K2 and K3 are opened, corresponding to the situation where the voltage stabiliser is not in use. When the voltage stabiliser has to be put to use, K1 and K2 are opened and K3 closed.

Figures 6 and 7 illustrate in more detail a single-phase voltage stabiliser. T1 is the autotransformer with series winding S between terminals 1-2 and 3, and with parallel winding P between terminals 1-2 and 4. This embodiment corresponds to that illustrated schematically in figure 2.

T4 is the variable inductance LR with working winding or main winding H between terminals 1 and 2, and control winding ST between terminals 3 and 4. Here the controllable inductance LR is coupled to the parallel winding P with terminal 2 on T4 coupled to terminal 4 on T1 (the embodiment corresponds to that illustrated in figure 2). The control current is fed from a controlled rectifier coupling U9 in figure 7 across terminal +/- to terminals 3 and 4 on the control winding ST in figure 6. The feedback of the output voltage from the voltage stabiliser's terminals R and S (figure 6) is connected to transformer T7 (figure 7) terminals 2 and 1 which gives a feedback signal to the rectifier regulator U8 (figure 7). Set-point adjustment, i.e. the desired voltage value is set from potentiometer R8 (figure 7). The supply voltage to the rectifier U9 is removed from terminal X4 (figure 6).

This voltage regulator connection with inductance LR in series with the parallel winding P on the autotransformer T1 is implemented by a voltage across the parallel winding P in T1 regulated by the inductance T4 being transformationally connected in series with the line voltage LI – LU between input terminal X1:1 (figure 6) and output terminal X1:7 (figure 6), thereby increasing the line voltage of the load that

will be coupled to R and S on X1:7 and X1:10 (figure 6). If the difference between feedback signal and set-point is large, the regulator will increase the control current to the inductance T4, thereby increasing the additional voltage which compensates the voltage drop. And conversely, if the additional voltage is too high, the power will decrease, downwardly adjusting the voltage added to the line voltage and thus keeping the output voltage of the load approximately equal to the set-point voltage.

Figure 8 illustrates in more detail a second single-phase voltage stabiliser. T1 is the autotransformer with series winding between terminals 1-2 and 3, and with parallel winding between terminals 1-2 and 4. This voltage stabiliser corresponds to the embodiment of the invention which was described in broad outline in connection with figure 4.

T4 is the variable inductance with main winding between terminals 1 and 2, and control winding between terminals 3 and 4. The main winding T4:1 of the controllable inductance is coupled to the series winding's output terminal T1:3. The control current is fed from a controlled rectifier coupling U9 in figure 7 across terminal +/- to terminals 3 and 4 on the control winding ST (figure 8). The feedback of the output voltage from the voltage stabiliser's terminals R and S (figure 8) is connected to transformer T7 terminals 2 and 1 (figure 7) which gives a feedback signal to the rectifier regulator U8 (figure 7). Set-point adjustment is set from potentiometer R8. The supply voltage to the rectifier U9 (figure 8) is taken from terminal X4 (figure 7).

This voltage regulator connection with inductance LR in series with the series winding's S output on the autotransformer T1 is implemented by the upwardly transformed output voltage from T1 (outgoing line voltage) being regulated by means of a controllable inductive voltage drop across the inductance T4 which lies in series in the line.

If the difference between feedback signal and set-point is large, the regulator will increase the control current to the inductance T4, thereby decreasing the voltage drop over the inductance and compensating the voltage drop. And conversely, if the additional voltage is too high, the power will decrease, increasing the voltage drop across the inductance to the line voltage and thus keeping the output voltage of the load approximately equal to the set-point voltage.

Figure 9 illustrates in more detail a third single-phase stabiliser. T1 is the autotransformer with series winding between terminals 1-2 and 3, and with parallel winding between terminals 1-2 and 4. This embodiment corresponds to that illustrated schematically in figure 3.

T4 is the variable inductance with main winding H between terminals 1 and 2, and control winding ST between terminals 3 and 4. The controllable inductance T4:1 is coupled to the series winding S and the parallel winding's input terminal T1:1-2. The control current is fed from a controlled rectifier coupling U9 in figure 10 across terminal +/- to terminals 3 and 4 on the control winding ST. The feedback of the output voltage from the voltage stabiliser's terminals R and S is connected to transformer T7 terminals 2 and 1 (figure 10) which gives a feedback signal to the rectifier regulator U8 (figure 10). Set-point adjustment is set from potentiometer R8 (figure 10). The supply voltage to the rectifier U9 (figure 10) is taken from terminal X4 (figure 9).

This voltage regulator connection with inductance in series with the series winding's input and the parallel winding's input on the autotransformer is implemented by the ingoing line voltage to the autotransformer being regulated by means of a controllable inductive voltage drop across the inductance T4 which lies in series in the line.

If the difference between feedback signal and set-point is great, the regulator will increase the control current to the inductance T4, thereby decreasing the voltage drop across the inductance and compensating the voltage drop. And conversely, if the additional voltage is too high, the power will decrease, increasing the voltage drop across the inductance to the line voltage and thus keeping the output voltage of the load approximately equal to the set-point voltage.

A three-phase embodiment for the single-phase solutions described thus far will be based on the same technical method of regulation with measurement of output voltage and comparison with a reference.

Figures 11 and 12 illustrate a three-phase embodiment of the single-phase solution in figure 9, where the inductances' T4, T5 and T6 control windings ST (figure 11) are connected in series and thereby are regulated equally (figure 12). A regulation for each phase in this connection will of course also be possible.

Figures 13 and 14 illustrate a three-phase embodiment of the single-phase solution in figure 8, where the inductances' T4, T5 and T6 (figure 13) control windings are connected in series and thereby are regulated equally. Once again a regulation for each phase in this connection will be possible if so desired.

Figures 15-18 illustrate a three-phase embodiment of the single-phase solution in figure 6, where each of the inductances T4, T5 and T7 (figure 15) has a separate regulating circuit. In this three-phase embodiment the phase sequence is important since the voltages in the series winding S are added vectorially to the phase voltage from the feed transformers to the line (not shown). The autotransformers for each

phase T1, T2 and T3 are indicated in a rather different manner from the previous drawings. The variable inductance T4 regulates the voltage to T1 with feedback signal from phase R-S (X1:10 and X1:12 in figure 15). Variable inductance T5 regulates the voltage to T2 with feedback signal from phase S-T (X1:12 and X1:14 in figure 15). Variable inductance T6 regulates the voltage to T3 with feedback signal from phase T-R (X1:14 and X1:10 in figure 15). In this manner the line voltages for each phase are regulated independently of one another.

Figure 16 illustrates regulation of the voltage in T1 by means of T4 and with desired value or set-point adjustment R8. The output signal (see bottom right in figure 16) is applied to the points 3 and 4 on T4 (figure 15). A corresponding regulation of T2 by means of T5 is illustrated in figure 17 with set-point adjustment R10, and regulation of the voltage in T3 by means of T6 is illustrated in figure 18.

PATENT CLAIMS

1. A system for voltage stabilisation of power supply lines, characterised in that it comprises an autotransformer with a series winding and a parallel winding, a variable inductance coupled to the autotransformer, and a control system for controlling the variable inductance with the object of automatically compensating for voltage variations in the power supply line.

2. A system according to claim 1, characterised in that the variable inductance comprises a magnetic core with a main winding and a control winding, the windings being wound round the core about two orthogonal axes.

3. A system according to claim 2, characterised in that the autotransformer's series winding (S) is arranged for connecting in series with the power supply line (L1-R), that the parallel winding (P) is arranged for series connection with the inductance's main winding (H) and with the second phase (L2) via a variable inductance (figure 2, figure 6).

4. A system according to claim 2, characterised in that the variable inductance (LR, T4) and the series winding (S) are connected in series with the power supply line (L1 – LU, L1 – R) and that the variable inductance is connected on the incoming line's side, and that the parallel winding (P) is connected directly to the next phase (L, S) (figure 3 and figure 9 respectively).

5. A system according to claim 2, characterised in that the variable inductance (LR, T4) and the series winding (S) are connected in series with the power supply line (L1 – LU, L1 – R) and that the variable inductance is connected on the outgoing line's side, and that the parallel winding (P) is connected directly to the next phase (L, S) (figure 4 and figure 8 respectively).

6. A three-phase system for voltage stabilisation, characterised in that it comprises a system according to claim 3 or a system according to claim 4 or a system according to claim 5 for voltage stabilisation of each phase (figures 11-18).

7. A three-phase system according to claim 6, characterised in that the control windings for three phases are connected in series and regulated together (figures 11-14).

8. A three-phase system according to claim 6,
characterised in that the control windings for the three phases are controlled independently of one another (figures 15-18).